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Visual Aids for Landing in Bad Visibility with Particular Reference to the Transition from Instrument to Visual Flight

By E. S. CALVERT, B.Sc., A.R.C.Sc.I.

Summary

It has been known for many years that in bad visibility the transition from instrument to visual flight is difficult, and may be highly dangerous if the pilot is suffering from fatigue, but it is only in the last five years or so that the problem of finding patterns for the visual aids which would make the transition easy and safe has been systematically studied. This paper describes some of the illusions which occur at transition and shows that they can be largely prevented by using bars of lights running transversely across the approach zone. A brief account is given of the results which have been obtained on the Crossbar System of Approach Lighting under operational conditions.

A new theory of visual judgment, known as the "parafoveal streamer" theory is described, and from this the characteristics which are desirable in the visual aids are deduced. The crossbar and slopeline systems of approach lighting are compared in the light of this theory, and it is concluded that the ordinary run of pilots will find the crossbar system easier to use because the mental processes necessary for its interpretation are those which the pilot has built up in good weather flying. It is emphasised that in the absence of any coherent theory of how visual judgments are made, it is almost impossible to evaluate the various systems in a reasonable time, and that if international standardisation is to be achieved, some theory must eventually become generally accepted.

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(1) Introduction

The two electronic approach aids which are now in fairly general use, namely, the Instrument Landing System (I.L.S.)†, and Ground Controlled Approach (G.C.A.)‡, enable a pilot who is adequately trained in instrument flying to bring his aircraft down to a height of about 200 ft., or about 3,500 ft. from the threshold of the runway. Below this height the pilot has great difficulty in following the signals because the distance which the aircraft travels in the time which it takes the pilot-aircraft combination to respond to them is large in comparison with the widths of the radio beam and the runway. This difficulty is still further increased if the air is rough, or the beam imperfect, of if, as frequently happens, the cross-wind component of the wind velocity varies with height.

If the meteorological visibility at heights below 200 ft. is one mile or more, then the pilot will see either the runway or the runway lights soon enough to enable him to make the necessary corrections visually and to land. If the visibility is much less than one mile the average pilot is unable to complete the landing safely unless the runway is equipped with high intensity approach and runway lights. By "high intensity" is meant intensities which are high enough to give useful ranges in daytime, i.e., intensities or more than 5,000 candles. (The highest intensities now being used are of the order of 100,000 candles, which is about as high as it is economic to go; beyond this point enormous increases in intensity are required in the limiting conditions in order to produce significant increases in range.)

If a better coupling unit is used with the I.L.S., such as either the Zero Reader or Automatic Approach, the aircraft can be brought down safely to about 100 ft., or about 1,300 ft. from the runway threshold. If the pilot does not see the ground before this he will have only a few seconds in which to sort out the ground indications, and the consequences of even a momentary misjudgment will be serious. Approach lights are therefore desirable, even in this case, so that the pilot can make visual contact with the ground at the earliest possible moment, and then monitor the approach by watching the lights. In the limiting visibility the visual aids which matter most are the runway lights and markings, and it is necessary for safety that both these and the approach lights give indications which the pilot can interpret instantly and instinctively, particularly when his real orientation is different from the subjective orientation which has grown up in his mind during the last phase of instrument flight. Unless this condition is met, improved electronic aids, short of automatic landing, may do little to lower the limiting visibility in which operations can be safely carried on, although they will still be of value in reducing the strain on the pilot.

In the past the visual aids have not given indications which could be interpreted instantly and instinctively, and there is little doubt that many accidents have been attributed to pilot error which should properly have been attributed to deficiencies in the visual aids. It has been known for many years that in bad visibility the transition from instrument to visual flight is difficult, and may be highly dangerous if the pilot is suffering from fatigue, but it is only in the last five years or so that the problem of finding the best patterns for the visual aids has been systematically studied. This paper describes the methods which have been used to attack this problem and indicates how the results obtained affect the design of the high intensity visual aids which are now coming into use on the major airports of the world.

(2) Nature of Problem

Everyone who has the use of his eyes judges his position in space by observing the pattern formed by the objects around him, and finds his way about the world by

† Sometimes known as the Instrument Low Approach System (I.L.A.S.).
‡ Sometimes known as the Talk Down System.

noticing how this pattern changes. For instance, if the pattern seen from an aircraft flying over cultivated land is an extensive and slow moving mosaic of fields, then the observer knows that he is high over the ground. Furthermore, if a particular point in the pattern appears stationary at a constant angular distance below the horizon, while other points in the vicinity appear to move radially away from it, then he knows that he is moving in a straight line towards that point. In a moving vehicle, the observer is carried by a framework which normally moves in a direction parallel to a line fixed with reference to the framework, and under normal conditions he can find the direction in which the vehicle is moving by noticing what part of the pattern occupies the position which represents dead ahead. In other words, the framework tells him the direction in which the vehicle is pointing, and is therefore an essential part of the total pattern. In an aircraft this framework may be represented by two lines, one real and one imaginary. The real one is the line representing the downward limit of the pilot's field of view. The imaginary one is the trace of the plane through the pilot's viewpoint parallel to the plane of symmetry of the aircraft.

For the purpose of this discussion the total pattern from which the pilot draws his information may be regarded as being made up of two elements, one structural and one textural. The structural element consists of the horizon and the approach or runway lighting pattern, together with natural landmarks such as plains, mountains, rivers, roads and railways, all these being seen within the framework provided by the wind and side screens. The textural element consists of trees, stones, grass, etc., and on an aerodrome, the markings on the surface of the runway and the actual light fittings if these have appreciable size. The structural element enables the observer to judge his position in the total pattern, the direction of his movement relative to it, and his attitude in pitch, yaw and roll. The structural element is, therefore, important at long ranges and in good visibility. The textural element enables the observer to judge his proximity to various objects, and is therefore important at short ranges and in poor visibility. The visual aids may, therefore, be defined as lights and markings laid out on the ground in such a manner that their general pattern and texture assist the pilot to make those judgments of position, attitude and direction of motion which are necessary in order that he may approach the runway, land on it, and taxi to the unloading point. Finding the best patterns for the visual aids in bad visibility is, therefore, a problem involving both perspective geometry and applied psychology, but the people who work on it are usually either pilots or illuminating engineers. Perhaps it is not surprising that the position as regards international standardisation is somewhat chaotic.

(3) Methods of Attacking Problem

(3.1) Full Scale Tests

The obvious method of attacking the problem is to lay down various patterns full scale, and then try to land on them in low visibilities. Shortly after the end of the war the Landing Aids Experiment Station was set up at Arcata, California, solely for this purpose, and, up to the present, has evaluated about six types of pattern at a cost of nearly $10,000,000.* In the conditions which obtained in this country at the end of the war it would have taken a year or more to design and manufacture the fittings for a new system, another year to obtain wayleaves and install it, and at least one year to evaluate it, at the end of which time, it might have been found that the system was unsatisfactory. Full scale testing of this kind is therefore slow, costly and dangerous. In addition, it has the disadvantages, firstly, that it is difficult to ensure that the various systems are compared under the same conditions, and secondly, that it is almost impossible to say how much guidance was in fact supplied by the visual aid in any particular landing, since a very skilful and experienced pilot (and it is only such pilots

* Figure given by leader of U.S. delegation to meeting of A.G.A. Division of I.C.A.O., November, 1949.

who can reasonably be asked to do the trials) can land with little help from the visual aids, provided that he has made a good radio approach and does not have to make corrections at the last moment. For these reasons many military and civil pilots have refused to accept the results obtained at Landing Aids Experiment Station as representative of operational conditions, although the methods of evaluation used are as objective as human ingenuity can make them. This trouble is, of course, always met with in any investigation which involves human habits and intuitions.

Another trouble is, that if flight trials are used to evaluate various systems without at the same time attempting to develop a coherent theory as to how the pilot makes his judgments, then the trials are likely to drag on for many years because new patterns can be invented as fast as the old ones can be evaluated. This is actually happening in some foreign countries at the present time, and, largely as a result of this, the international standardisation which is so necessary for the safety of air transport is not yet in sight. It is, therefore, necessary to develop methods of weeding out the bad systems and demonstrating their shortcomings without the expense and delay of full scale trials. This has been achieved, and it is now possible to select those systems which show most promise, and to confine the flight trials to them. The application of these methods to this problem has saved this country much time and money, but it is believed that the ideas behind them have a bearing on many other problems in illuminating engineering.

(3.2) Perspective Analysis

The first of these methods may be called "perspective analysis." It consists of making diagrams, known as "perspective diagrams," which show in outline the structural element of the pattern under consideration, that is, the horizon, the runway or approach lights and the two lines which represent the framework formed by the edges of the windscreen. These diagrams, which may be considered as calibrated photographs with the detail taken out, are made for various stages in the approach and for various errors. As this method cannot adequately represent the effects of motion, care must be exercised when drawing conclusions from it. Nevertheless, the making of such diagrams is an indispensable mental discipline to which all who would work fruitfully on this problem must submit themselves. The method of making these diagrams has been described by the writer in a previous paper (1).

(3.3) Kinematic Simulation

The second method may be called "kinematic simulation." In this a laboratory instrument is employed to simulate the views which the pilot would see during the approach and landing. An instrument of this kind, invented by Sparke and Ringe of the Royal Aircraft Establishment, is shown on Fig. 1. In this instrument a set of controls similar to those of an aircraft are connected to the slide of an optical projector. This projector throws a moving image of the pattern under test on to a screen, and the observer views this image through an eyepiece. When he operates the controls, he sees lights which appear to move in exactly the same way as real approach lights on the ground would move, if he were in a real aircraft, and operated the aircraft controls in a similar sense. The field of view can be made the same as any particular type of aircraft, and the initial approach errors, the visibility conditions and the magnitude of the cross wind can also be changed at will. This particular simulator is very realistic, and much valuable research work has been done with it. Demonstrations have been given to many hundreds of people, and this has done more than almost anything else to produce agreement between pilots, engineers and adminstrators on approach and taxiway lighting policy. Certainly, many differences of opinion, which in other countries have led to years of inconclusive and acrimonious discussion, have been amicably settled.

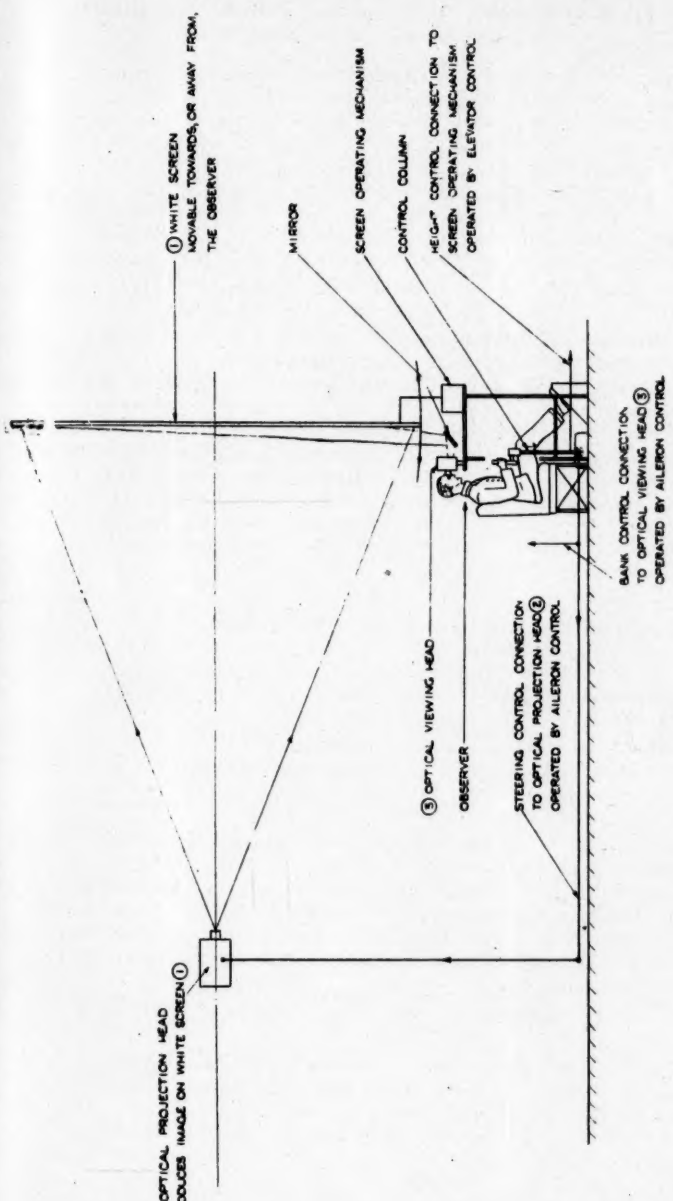

① WHITE SCREEN MOVABLE TOWARDS, OR AWAY FROM, THE OBSERVER
MIRROR
SCREEN OPERATING MECHANISM
CONTROL COLUMN
HEIGHT CONTROL CONNECTION TO SCREEN OPERATING MECHANISM OPERATED BY ELEVATOR CONTROL
⑤ OPTICAL VIEWING HEAD
OBSERVER
STEERING CONTROL CONNECTION TO OPTICAL PROJECTION HEAD ② OPERATED BY AILERON CONTROL
BANK CONTROL CONNECTION TO OPTICAL VIEWING HEAD ⑤ OPERATED BY AILERON CONTROL
② OPTICAL PROJECTION HEAD PRODUCES IMAGE ON WHITE SCREEN ①

Fig. 1. Instrument for simulating approaches in bad visibility.

(4) Requirements for Visual Aid Patterns and Illusions Caused by Failure to Meet Them

In order to be successful as a visual aid in bad visibility a pattern must be both geometrically sufficient and psychologically acceptable to an observer who is moving at high speed and is in the middle of a very harassing task. (Some idea of how harassing this task is may be obtained from the observations on flying the I.L.S. localiser given in Appendix I to this paper. In other words, the pattern must not only contain sufficient indications to make the aircraft's position, attitude, angular rotations, and direction of motion geometrically determinate; it must give these indications in a form which the pilot can assimilate instantly and instinctively in moments of mental stress. This means that he must, as far as possible, be able to use the same habits of thought as he normally uses in good visibility, because, when hard pressed, he will revert to them.

The first approach lighting systems to be tried did not meet these requirements, and some of them were, perhaps, as much a hazard as an aid in bad visibility in that they were capable, in certain circumstances, of producing illusions and misjudgments at the moment of transition from instrument to visual flight. It is hard to get to the bottom of these illusions, because all of them are difficult to put into words, and some are irrecoverable after the moment of occurrence. As they have to be experienced to be appreciated, pilots are naturally a little chary of discussing them with non-pilots whose only knowledge of the subject will probably be derived from driving a motor car, and who will be unable to visualise the disturbing effect of moving with six degrees of freedom instead of three. There are, however, three illusions which are commonly reported as follows:—

(a) the runway lights appear to "float in space," or "stand on end," i.e., they appear as an inverted vee in the vertical plane, instead of a pair of parallel lines in the horizontal plane. Or it may be complained that the pattern has "no depth," and that it appears to be at a varying distance from the observer. As a result, the pilot "loses his ground plane" and may have a strong impulse to pull up.

(b) The approach lights appear to "swing from side to side" or "drift away out of the field of view." As a result, the pilot finds it impossible to descend on a straight course on the visual aids alone and "weaves" from side to side.

(c) An almost irresistible impression of the horizon direction may suddenly build up in the pilot's mind in spite of the fact that he knows that he cannot tell where the horizon is unless he refers back to his instruments, a procedure which may not be possible in the short time available. When the pilot is in a state of stress, this additional mental conflict may cause feelings of confusion and frustration and, in extreme cases, of vertigo.

(5) Methods of Preventing Illusions at Transition

(5.1) Texture

Tests made from a captive balloon in thick fog indicate that illusion (a) is largely due to lack of texture, i.e., to the use of small light fittings and the failure to mark the surface of the runway with bold markings of high contrast. (The starlit sky provides examples of patterns which, because of the absence of texture, do not appear to lie in any particular plane.) The reason for this is that we are accustomed to recognise the ground plane from the fact that objects such as trees, shrubs, houses, etc., whose real size we know, subtend smaller and smaller angles as their distance from the observer increases. Quick recognition of the ground plane is probably

the most useful effect of texture, but as mentioned in Section 2, it also provides indications of proximity to the ground which are of great value. In the case of the approach lights, texture can be supplied by using fittings of appreciable size arranged in groups in the vertical plane perpendicular to the centre line. If the lights are in this plane, and are spaced at a constant distance from one another, then the angular subtenses of both the lights and the spaces are proportional to the distance of the group from the observer. It is this which produces the impression of a plane. An important conclusion from this is that if the approach lights flash, these "depth" impressions will be upset. Extensive flight tests made in America have fully confirmed this, and as a result, trials are now in progress using flashing lights superimposed on a pattern of fixed lights. In the writer's opinion flashing lights used in this way serve no useful purpose except that of identification, and this can be better achieved by distinctiveness of pattern.

(5.2) Pattern of Lights

The other two illusions are largely due to geometrical deficiencies in the structural element of the approach lighting pattern. The pattern which has been most widely used is a line of lights offset to the left of the extended centre line of the runway and parallel to it. Let us, therefore, apply the method of perspective analysis to the case of an aircraft flying parallel to a line which, for the sake of simplicity, may be regarded as extending to infinity. If there is a horizon, and if the aircraft is unbanked, then the pilot will see a picture such as that shown by the full lines on Fig. 2. In this figure, the angle θ which the perspective projection of the line makes with the vertical is $\tan^{-1}(w/h)$, where w is the lateral distance between the aircraft and the line, and h is the height of the pilot's head. As this angle is important, it will be referred to in what follows as the "perspective angle" of the line.

If distant aiming points are blotted out by fog the pilot will have to estimate his lateral distance from the line by observing its perspective angle, but since this is a function of height as well as lateral distance, he will have no means of knowing whether a change in it is due to a change in height or to a change in lateral distance. He will, therefore, be unable to fly on a straight course parallel to the line and at the same time lose height. There are two ways in which this ambiguity can be resolved; a pair of lines symmetrically disposed about the centre line may be used, or, alternatively, a single line along the middle. Of these, the single line is preferred for three reasons; firstly, because it gives far more sensitive indications of alignment, particularly at low heights; secondly, because it avoids the difficulty of positively identifying the lines; and, thirdly, because it is easier to use. With a single line along the middle the perspective angle is zero when the lateral error is zero, whatever the height, and the pilot's task is then the manageable one of straddling the lights, that is, keeping the perspective projection of the line vertical when the aircraft is unbanked.

(5.3) Horizon Indication

There is, however, a much more serious ambiguity in the ground indications. If the aircraft is straddling the line but is banked by the angle θ, then, if there is a horizon, the pilot will see a view such as that shown by the full lines on Fig. 3. It will be noted that *if the horizon is removed from Figs* 2 *and* 3, *they become identical.* It follows that in bad visibility the pilot cannot instantly know by looking at the ground indications whether the aircraft is banked or laterally displaced, *but he will know* that it is one or other or both and that he must act immediately. In order to make a decision, he must know the horizon direction, and if this is not supplied by the ground indications, a false one will be supplied by his mind, because without it no decision is possible. If he decides that the aircraft is laterally displaced, when it is in fact banked, he will put on more bank, in order to correct the imaginary displacement, and may then lose control or touch the ground with his wing tip. If

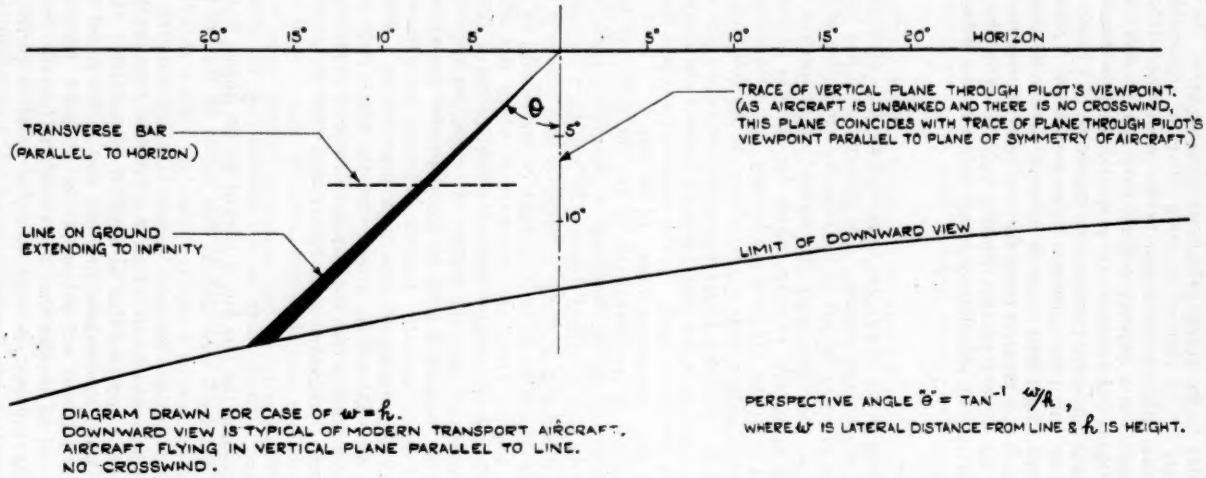


Fig. 2. Perspective diagram showing view seen by pilot when aircraft is displaced to right of line but is not banked.

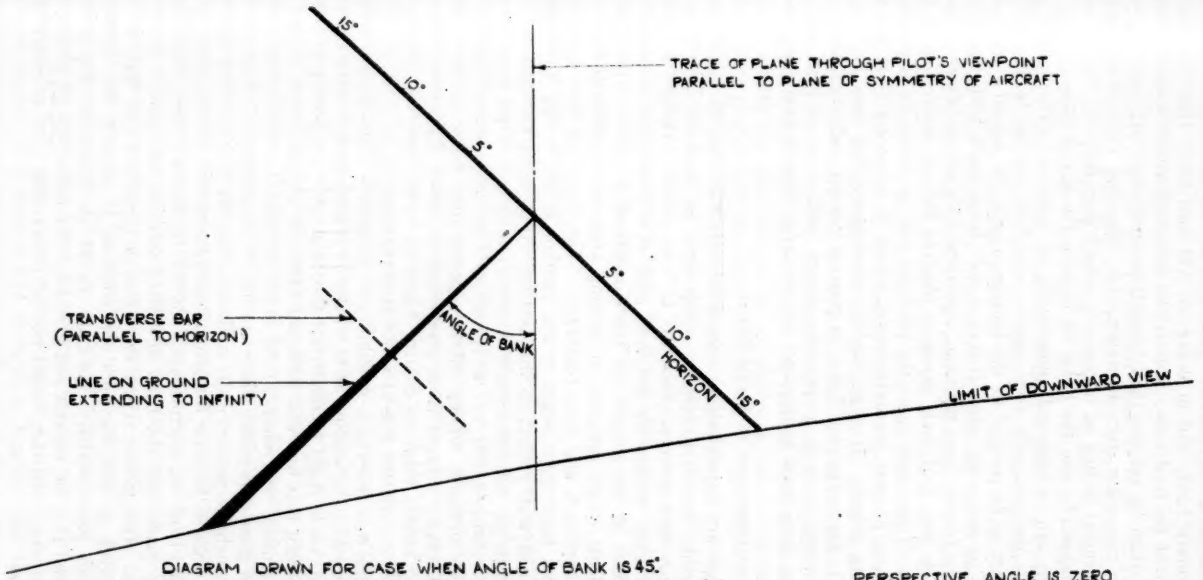


Fig. 3. Perspective diagram showing view seen by pilot when aircraft is vertically over line and is banked left wing down.

he decides that the aircraft is banked, when it is in fact laterally displaced, he will take off the imaginary bank, and in doing so, will turn away from the line, which will then drift out of his field view. Pilots who are experienced in all-weather flying cope with this situation by keeping their corrections small and very carefully watching the effect of each correction over an appreciable time, but even they cannot avoid weaving and the general feeling of uncertainty which goes with it. On the simulator some non-pilots habitually lose the lights by turning the wrong way.

This ambiguity can be removed quite simply by means of bars of lights running transversely across the approach zone, since these bars appear to the pilot of an approaching aircraft to be parallel to the horizon, unless the lateral error is so great that the direction in which he looks makes a very large angle with the centre line. In Figs. 2 and 3 the broken lines represent transverse bars perpendicular to the centre line, and it will be seen that their presence resolves the ambiguity just as the real horizon would do. These bars show the pilot the rate at which he is putting on or taking off bank, and provide the anticipation which is so necessary in steering any type of fast-moving vehicle. It is particularly emphasised that their function is just as much to enable the centre-line lights to provide correct indications of alignment and its rate of change, as it is to provide correct indications of bank and its rate of change, vital as these bank indications are for large aircraft near the ground.

(5·4) Transition from Instrument to Visual Flight

Nearly all pilots are consciously or sub-consciously aware of the confusion caused by failure to provide bank indications which can be instantly recognised. One example has already been given in Appendix I. As another example, we may quote a passage from a letter written by the chief pilot of a European continental airline, to the representative of his country on the Council of I.C.A.O. This letter refers to six fatal accidents which occurred at landing after what appeared to be a good G.C.A. or I.L.S. approach, and then continues: "The causes of these accidents seem to be complex, but have their origin in my opinion in the wrong interpretation of lights on the ground with respect to the horizon. It is remarked that the visibility at the moment when the accidents occur is *always sufficient to see a series of lights. This condition is indispensable to the production of the optical illusion.*" The prevalence of such opinions among pilots suggests that many of them feel it to be unsafe to make the transition from instrument to visual flight until they can see enough ground to enable them to control bank, i.e., until they can see how much bank they have got on and the rate at which it is changing.

The knowledge that there is a possibility of dangerous illusions probably lies at the root of the long-standing dispute as to whether the pilot should make the transition from instrument to visual flight gradually, or should go over completely to visual flight as soon as the co-pilot tells him that sufficient lights are visible. After having listened to many pilots discussing this question, the writer is inclined to think that *if the visual aid is safe*, i.e., if it gives indications which are free from ambiguity, which can be easily interpreted, and which are geometrically sufficient, then the way in which the transition is made does not matter, because the ground indications will never appear to conflict with those obtained from the instruments. As will be shown below, visual judgments at high speed are made with the head in a fixed position and mainly by parafoveal vision. The ideal arrangement might therefore be to project the flight information on to the windscreen so that the pilot can continue to observe this foveally while observing the lights parafoveally. As Capt. A. M. A. Majendie* has pointed out, the transition would then be smooth and gradual. The difficulties of windscreen projection are an old story, but they might not be insuperable with an instrument such as the Zero Reader.

* Senior Operational Captain, B.O.A.C.

(6) Method of Providing Elevational Guidance

(6.1) Recommended Pattern of Lights

These arguments lead to the conclusion that, in order to prevent illusions at transition and provide sensitive indications which can be easily interpreted by the average pilot, the approach lighting pattern should consist of a centre line with bars running transversely across it at intervals. Such a pattern will obviously indicate lateral error, heading, bank and proximity to the ground, and by coding the centre line, it can easily be made to indicate distance from the threshold of the runway. There remains, however, the problem of how to provide elevational guidance, that is, how to indicate whether or not the aircraft is losing height at a rate which will bring it over the threshold at a suitable height for safe landing. For this the pattern must be such that a pilot seeing only a portion of it, say 1,000 ft., will be able to tell either whether he is overshooting or undershooting a desired aiming point (which may be a mile ahead), or alternatively, whether he is following some desired approach path such as the extension of the electronic glide path. In America the view which is generally accepted is that the extension of the electronic glide path should be indicated, and that this is the most important indication of all. In Britain the view which is generally accepted is that, since the rate of descent is already fixed within close limits during the radio portion of the approach, all that is required for the few seconds that the pilot is over the approach lights is a rough indication of aiming point, combined with distance marking and a good indication of proximity to the ground. It is also considered that, in the limiting conditions, geometrically exact indications of an ideal approach path are of little value because they cannot be assimilated and acted on in the short time available. In Britain the emphasis is, therefore, on good alignment and proximity indications, and above all, on ease of transition from instrument to visual flight.

(6.2) Converging Line Principle

All the known methods of providing elevational guidance additional to the proximity indications supplied by the textural element of the pattern are based on the principle that the sum of the perspective angles of a pair of lines on the ground which converge to the selected aiming point is constant for all viewpoints on any straight approach path which passes through this aiming point. In Fig. 4 the lines OX and OY on the ground converge at an angle 2β to the point O. Fig. 5 shows the views of these lines as seen by the pilot from points on three approach paths, $a/2$, a and $2a$, all passing through O. If the pilot can fly so as to keep the apparent angle between these lines constant, then he is following a path which will intersect the runway at O. If, in addition, he can fly so as to keep this angle constant at a certain predetermined value, which by training he has learned to memorise, then he will be following a particular approach path. For example, if he wishes to approach at an angle equal to half the angle of convergence of the lines on the ground, then the sum of the perspective angles must be kept at 90 deg.

The accuracy with which this apparent angle can be judged decreases progressively as the visibility becomes worse, because less and less of the two legs which define it can be seen. Furthermore, the pilot knows that the pattern is really a pair of nearly parallel lines, and he tends to see it as such in his "mind's eye," whatever the shape of the perspective image. (This distortion of the perspective image by the mind has been investigated by Prof. Thouless of Cambridge, and has been called by him "phenomenal regression.") A pair of converging lines, therefore, gives a poor indication of the aiming point, and a poorer indication of a particular approach path. Indeed, as explained above, pilots tend in bad visibility to hug one line and ignore the other, because this is the easiest way to follow a line and at the same time to lose height.

Fig. 4. Plan and elevation corresponding to perspective diagram shown in Fig. 5.

Fig. 5. Perspective diagram showing lines OX and OY from viewpoints A, B and C vertically over centreline.

(6.3) Transverse Bar Principle

If, however, the lines OX and OY are replaced by transverse bars whose ends lie on these lines, as shown diagrammatically in Fig. 6, then a reasonably accurate judgment of the aiming point can be made. In this case there are two indications available to the pilot for the making of this judgment. The first is supplied by the angular subtense of the bars. If the aircraft is flying down a straight path which intersects the runway at O, then the angular subtense of each bar, as it disappears underneath the cut-off line, will appear to the pilot to remain constant. If the angular subtense increases, then the aircraft is undershooting the point O; if it decreases, then the aircraft is overshooting the point O. It should be noted that the aircraft is not tied to a particular glide path fixed in space and that, in all cases, it is brought down to the point O from wherever the pilot first sees the lights. In order to come down a particular path the pilot has to be able to memorise the corresponding angular subtense, and it is likely that all pilots can do this within limits. Perhaps in the future some form of simulator will be used for testing and developing the faculty of visual memorisation.

The second indication is supplied by the apparent downward movement of the bars. This tells the pilot whether he is flying over the system or into it because, if he is flying into it, the bar which he is going to hit will cease to move downwards, and those further away will move upwards instead of downwards. Evidence has been

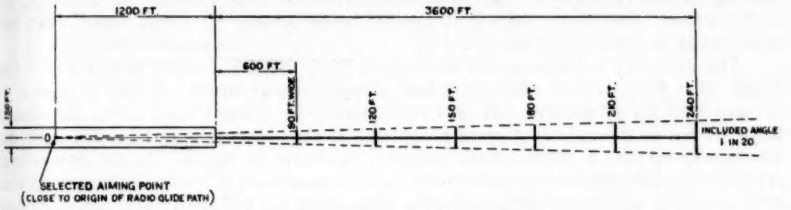


Fig. 6. Crossbar pattern. (Diagrammatic.)

accumulating during the last year or so which tends to show that this indication is the more important, and that it is the kind of indication which is relied on most by the driver of any fast moving vehicle. It is discussed in more detail at the end of this paper in connection with the parafoveal streamer theory of visual judgment.

(7) Results of Operational Experience on Crossbar System

The theoretical work described above was completed by the end of 1946. It was realised, however, that the principles evolved would have to be demonstrated more convincingly if they were to gain general acceptance, and after that date the main effort of those working on the problem was directed towards producing a realistic simulator. This simulator (now known as "the cyclorama"), was completed in October, 1947, and an almost continuous series of demonstrations was given on it during the following six months. As a result, mainly of these demonstrations and the balloon tests, the Ministry of Civil Aviation decided to install at London Airport a system based on the pattern shown on Fig. 6, without waiting for the completion of the flight trials.

This system, which has now come to be known as the Crossbar System, or sometimes as the Calvert System, became operational in November, 1948. The first installations on the Air Lift became operational about the same time and, in a few months, nearly a dozen installations had been completed, the record time for an installation being 11 days. Reports from pilots, both civil and military, have been consistently favourable and often enthusiastic, and landings with passengers have been made in daylight in visibilities as low as 300 yards. This experience, most of which

was gained with average pilots in conditions of high traffic density, seems to point to the conclusion that an indication of the horizon direction is necessary for a number of physiological reasons as well as for the ones given above. A concise account of the physiological aspects of the problem can be found in a paper by Dr. K. G. Bergin. (7)

(8) Slopeline System of Approach Lighting

The most interesting of the many approach lighting systems which have been tested at Arcata is the Slopeline System, sometimes known as the Pearson-Sweet System. This system is expensive, both to install and operate, and it is therefore likely that its use will be confined to large airports where a high traffic density either exists already or is expected in the near future.* The first operational installation, that at New York International Airport, Idlewild, was completed in late 1949, and three others are reported to be nearing completion. In addition to its expense, the fittings used in this system constitute obstructions in the approach area, and it is therefore unlikely that the system will be used on military airfields.

The system is shown in Fig. 7. It takes its name from the fact that it uses "slopelights," a slopelight being a pole with a number of equally spaced lamps on it, the pole being set up at 45 deg. to the horizontal. (In the system as agreed at the meeting of the Aerodrome, Air Routes and Ground Aids Division of I.C.A.O., held in November, 1949, each slopelight had 10 lamps spaced 17 inches apart, each lamp being rated at about 250 watts.)

The best way to examine the indications given by this pattern is to make a small model of it by means of pins stuck into a piece of soft wood. If this is done it will be seen that the slopelights fall into two continuous straight lines when the observer is anywhere on the indicated approach path. If the observer is not on this path, each line breaks up into a characteristic echelon, as shown in Fig. 8. As the two echelons are not very different, and are affected by lateral departures from the indicated approach path as well as by vertical departures, the indications are difficult to sort out in moments of mental stress and considerable practice is required before they can be interpreted without conscious mental effort. This difficulty may be partly due to the fact that the indications differ in kind from those given by the instruments, i.e., the visual system indicates which of the four quadrants the observer is in, whereas the instrument system indicates distances from real or imaginary planes.

The biggest disadvantage of this indication is that the two echelons have to be observed simultaneously in order to obtain the glide path indication. If the aircraft is below the indicated glide path, then the apparent horizontal angle between the two echelons at the points where they intersect the cut-off line may be as much as 50 deg. In limiting conditions, therefore, an observer moving at high speed will find it almost impossible to observe and interpret this indication, and is more likely to make his elevational judgments from the texture of the system, which is good, and from the horizontal angle between the echelons. This process is analogous to observing the texture of a crossbar and its angular subtense, but the crossbar system has the additional advantages that it gives bank indications at the same time, together with unambiguous and far more sensitive indications of lateral error. If crossbars are added to the slopeline system, as has already been done at Arcata, then there may possibly be little to choose in performance between the two systems *for pilots who have become thoroughly accustomed to them.* The ordinary run of pilots will, however, find the crossbar system easier to use, because the mental processes necessary for its interpretation are those which have been built up in good weather flying. It is therefore likely that the crossbar system will have a better safety record under operational conditions, and that this, combined with the fact that it is cheaper to install, will gradually lead

* In July, 1949, the American Air Line Pilots' Association put forward a centre line system which has one crossbar in the approach, and several near the threshold. This is now being tested at Arcata.

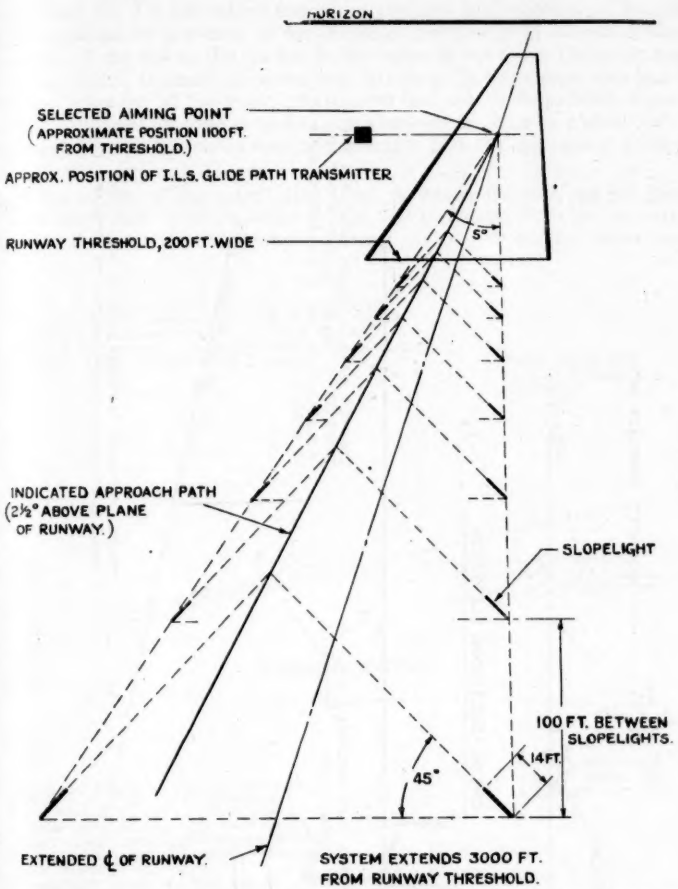


Fig. 7. Slopeline system. Above is a true perspective view from a point 1,000 ft. from threshold, 250 ft. high and 90 ft. to right of centreline.

to its general adoption. To illustrate this point, the indications given by the two systems are compared in Figs. 9 and 10.

(9) Parafoveal Streamer Theory of Visual Judgment

(9.1) Information derived from Kinematic Qualities of Visual Field.

During the early part of 1949 tests were made on the cyclorama to find the accuracy with which certain visual judgments could be made. It was found that when the angular velocity of objects in the visual field was large, the accuracy was higher than could be explained by the theory that the observer merely noticed the difference between the view which he saw in one situation and that which he saw in another situation. In other words, it appeared that the observer was deriving information from the kinematic qualities of the visual field. At the same time reports began

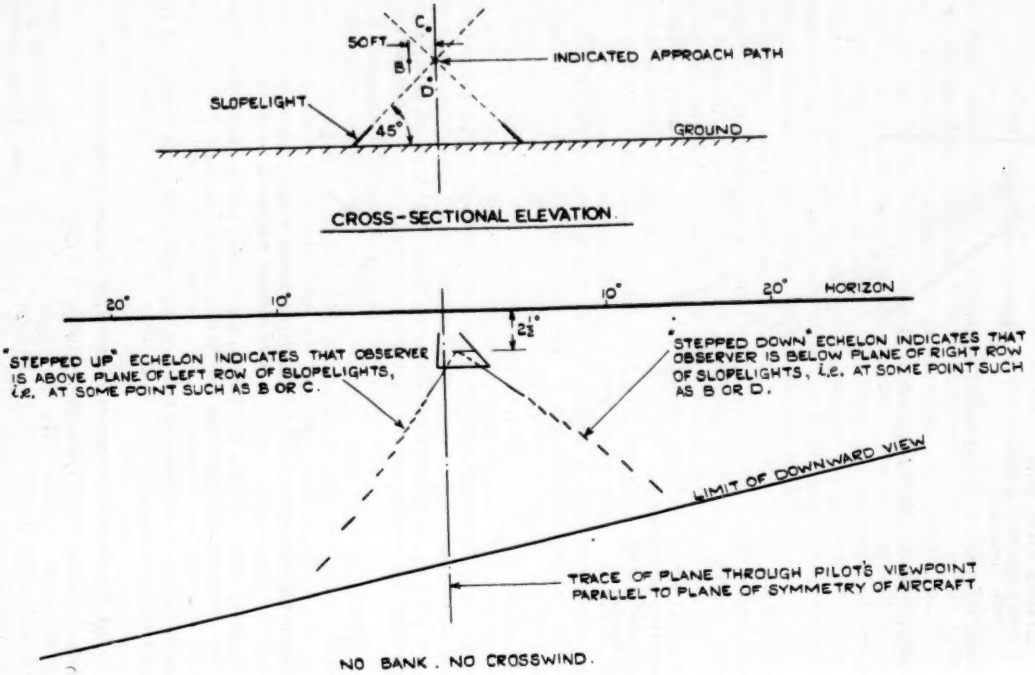

C
50FT
B
D
INDICATED APPROACH PATH
SLOPELIGHT
45°
GROUND
CROSS-SECTIONAL ELEVATION.
20°
10°
10°
20°
HORIZON
2½°
"STEPPED UP" ECHELON INDICATES THAT OBSERVER IS ABOVE PLANE OF LEFT ROW OF SLOPELIGHTS, i.e. AT SOME POINT SUCH AS B OR C.
"STEPPED DOWN" ECHELON INDICATES THAT OBSERVER IS BELOW PLANE OF RIGHT ROW OF SLOPELIGHTS, i.e. AT SOME POINT SUCH AS B OR D.
LIMIT OF DOWNWARD VIEW
TRACE OF PLANE THROUGH PILOT'S VIEWPOINT PARALLEL TO PLANE OF SYMMETRY OF AIRCRAFT
NO BANK. NO CROSSWIND.

Fig. 8. View of slopeline system seen by pilot from viewpoint 'B'.

to come in from the Air Lift which seemed to confirm this conclusion. For instance, the angular subtense of the bars in the crossbar installation at Gatow differed considerably from all the others, but, as far as the writer is aware, no comment was made on this by the pilots. (Indeed, the writer was unable to find any pilot who had noticed the difference, although all the pilots interrogated had used both patterns many times.) No pilot was conscious of using the angular subtense of the bars as a glide path indication, but every pilot stated, some very emphatically, that the elevational guidance was good.

About the middle of the year, Capt. A. M. A. Majendie (who did not then know of the above results) informed the writer that he was convinced from his own experience as a pilot that the most important impressions of the pilot at heights below about 150

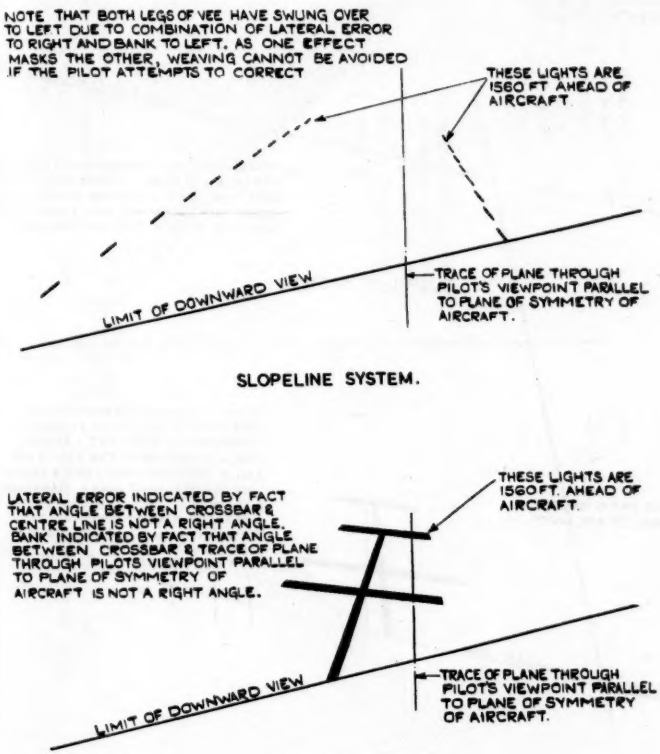
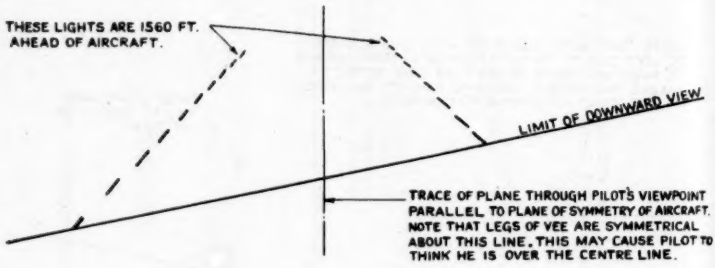

NOTE THAT BOTH LEGS OF VEE HAVE SWUNG OVER TO LEFT DUE TO COMBINATION OF LATERAL ERROR TO RIGHT AND BANK TO LEFT. AS ONE EFFECT MASKS THE OTHER, WEAVING CANNOT BE AVOIDED IF THE PILOT ATTEMPTS TO CORRECT
THESE LIGHTS ARE 1560 FT AHEAD OF AIRCRAFT
LIMIT OF DOWNWARD VIEW
TRACE OF PLANE THROUGH PILOT'S VIEWPOINT PARALLEL TO PLANE OF SYMMETRY OF AIRCRAFT.
SLOPELINE SYSTEM.
LATERAL ERROR INDICATED BY FACT THAT ANGLE BETWEEN CROSSBAR & CENTRE LINE IS NOT A RIGHT ANGLE. BANK INDICATED BY FACT THAT ANGLE BETWEEN CROSSBAR & TRACE OF PLANE THROUGH PILOTS VIEWPOINT PARALLEL TO PLANE OF SYMMETRY OF AIRCRAFT IS NOT A RIGHT ANGLE.
THESE LIGHTS ARE 1560 FT. AHEAD OF AIRCRAFT.
LIMIT OF DOWNWARD VIEW
TRACE OF PLANE THROUGH PILOTS VIEWPOINT PARALLEL TO PLANE OF SYMMETRY OF AIRCRAFT.
CROSSBAR SYSTEM.
AIRCRAFT IS AT GLIDE PATH HEIGHT & HEADING PARALLEL TO ℄, BUT IS 50FT. TO RIGHT. AIRCRAFT IS BANKED 7° LEFT WING DOWN, i.e. IS ABOUT TO CHANGE HEADING IN A DIRECTION WHICH WILL CAUSE THE LATERAL ERROR TO DECREASE.
HEIGHT 200 FT., 2½° GLIDE PATH, NO CROSSWIND.

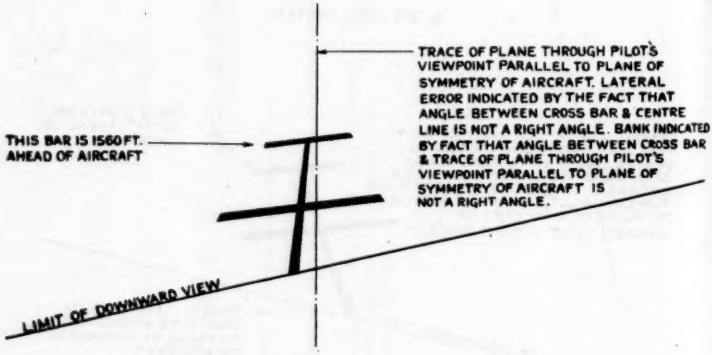
Fig. 9. Comparison of indications given by slopeline and crossbar systems.

Fig. 8. View of slopeline system seen by pilot from viewpoint B.

feet, were obtained from the kinematic qualities of the visual field, and in support of this view, pointed out that at low heights the pilot often stares straight ahead for quite a few seconds. In other words, there are relatively long periods during which his eyeballs are fixed as well as his head. The pilot may, of course, glance at his instruments, or even look for a moment at objects to one side of his path, but Capt. Majendie believed that when doing this the pilot was not actually engaged in making visual judgments of height and direction. A few months later, Capt. Majendie showed the writer a number of films which he had taken of pilots' faces when landing, and these confirmed his belief that during the landing operation there are relatively long periods during which the pilots' eyes do not move.


THESE LIGHTS ARE 1560 FT. AHEAD OF AIRCRAFT.
LIMIT OF DOWNWARD VIEW
TRACE OF PLANE THROUGH PILOT'S VIEWPOINT PARALLEL TO PLANE OF SYMMETRY OF AIRCRAFT. NOTE THAT LEGS OF VEE ARE SYMMETRICAL ABOUT THIS LINE. THIS MAY CAUSE PILOT TO THINK HE IS OVER THE CENTRE LINE.

SLOPELINE SYSTEM


TRACE OF PLANE THROUGH PILOT'S VIEWPOINT PARALLEL TO PLANE OF SYMMETRY OF AIRCRAFT. LATERAL ERROR INDICATED BY THE FACT THAT ANGLE BETWEEN CROSS BAR & CENTRE LINE IS NOT A RIGHT ANGLE. BANK INDICATED BY FACT THAT ANGLE BETWEEN CROSS BAR & TRACE OF PLANE THROUGH PILOT'S VIEWPOINT PARALLEL TO PLANE OF SYMMETRY OF AIRCRAFT IS NOT A RIGHT ANGLE.
THIS BAR IS 1560 FT. AHEAD OF AIRCRAFT
LIMIT OF DOWNWARD VIEW

CROSSBAR SYSTEM

AIRCRAFT IS AT GLIDE PATH HEIGHT & HEADING PARALLEL TO ℄, BUT IS 50 FT. TO RIGHT. AIRCRAFT IS BANKED 7½° RIGHT WING DOWN, i.e. IS ABOUT TO CHANGE HEADING IN A DIRECTION WHICH WILL CAUSE THE LATERAL ERROR TO INCREASE. HEIGHT 200 FT., 2½° GLIDE PATH, NO CROSSWIND.

Fig. 10. Comparison of indications given by slopeline and crossbar systems.

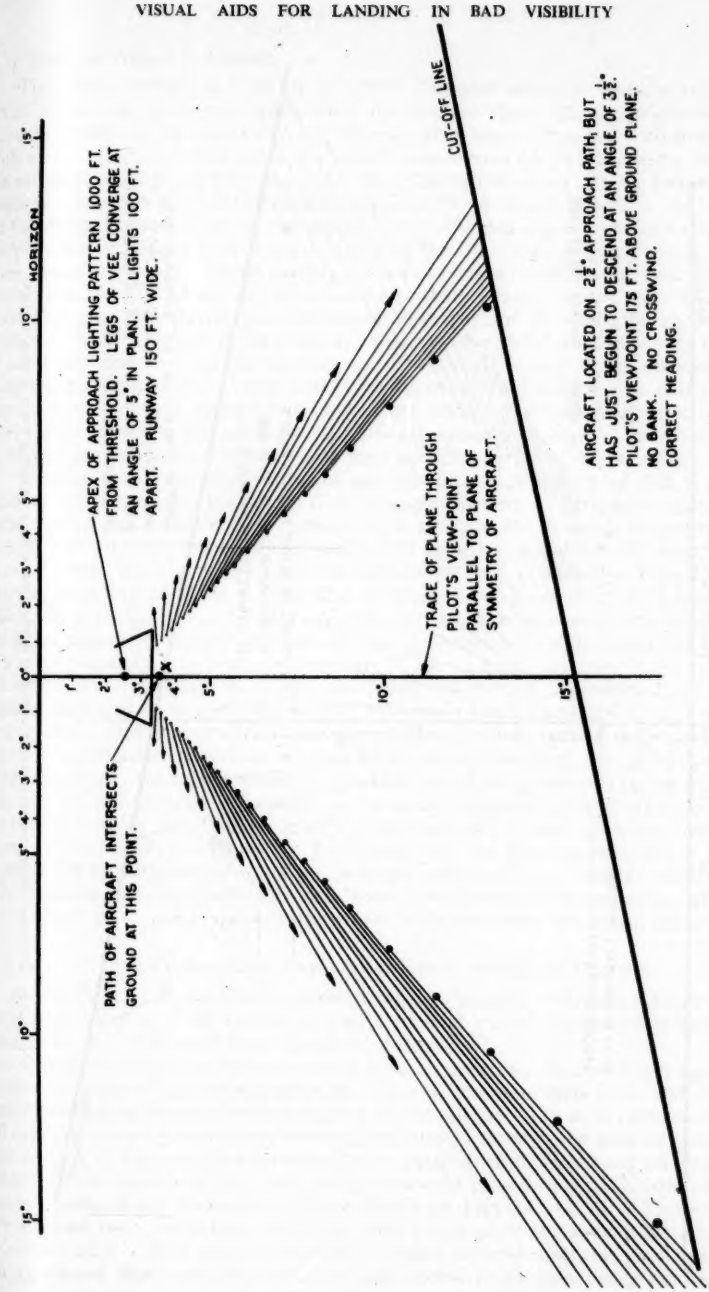

HORIZON
APEX OF APPROACH LIGHTING PATTERN 1000 FT. FROM THRESHOLD. LEGS OF VEE CONVERGE AT AN ANGLE OF 5° IN PLAN. LIGHTS 100 FT. APART. RUNWAY 150 FT. WIDE.
CUT-OFF LINE
TRACE OF PLANE THROUGH PILOT'S VIEW-POINT PARALLEL TO PLANE OF SYMMETRY OF AIRCRAFT.
AIRCRAFT LOCATED ON 2½° APPROACH PATH, BUT HAS JUST BEGUN TO DESCEND AT AN ANGLE OF 3½°. PILOT'S VIEW-POINT 175 FT. ABOVE GROUND PLANE. NO BANK. NO CROSSWIND. CORRECT HEADING.
PATH OF AIRCRAFT INTERSECTS GROUND AT THIS POINT.

Fig. 11. Streamer diagram for aircraft undershooting the threshold.

Fig. 12. Streamer diagram for aircraft crossing centreline with a heading error 5 deg. to left.

(9.2) Theory of Visual Judgment

This seems to lead to a theory of visual judgment which is roughly as follows: When the aircraft is several miles from the runway threshold, the angle which the pattern subtends at the pilot's eye and the rate of change of the perspective image are both small. The pilot then scans the pattern and makes his judgments by comparing the perspective image with an ideal one which he carries in his mind. (These are the conditions in which the echelon indications given by the slopeline pattern are effective.) As the aircraft comes closer to the pattern, the subtended angle becomes so large that the pilot can no longer scan it comfortably in the short time which remains. At the same time the rate of change of the perspective image rapidly increases. At some height, say 150 feet or so, the pilot begins to stare straight ahead with his eyeballs fixed, and after this derives his impressions of height and direction mainly from two sources. The first source is the pattern formed by the paths which the retinal images of the lights trace out on the parafovea. The second source is the velocity of the images along these paths. These paths may be called "streamers," the pattern which they form a "streamer pattern," and the image velocity the "streamer velocity." The theory itself may also be called the "parafoveal streamer theory." (The parafovea is, of course, what is commonly known as the "corner" or "tail" of the eye.)

In order to see the significance of this theory it is necessary to link it with the geometry of the landing operation. It is a simple theorem in perspective geometry to show that if an observer is in motion in a straight line towards a point X in a pattern, then all other points in the vicinity will appear to move radially away from X. In other words, the streamers all pass through the point X as shown on Figs. 11 and 12, and this gives the observer a good clue to where he is going even if X itself is not visible. It is thought that the pilot uses this indication to manoeuvre the aircraft until the lights appear to stream past steadily and symmetrically with respect to the trace of a plane parallel to the plane of symmetry of the aircraft. (If there is no crosswind, this plane passes through the pilot's viewpoint. If there is a crosswind, the trace is laterally displaced to leeward, the angular movement being equal to the angle of drift.) Having established a symmetrical streamer pattern, he then stares fixedly ahead at the origin of the streamer pattern as revealed by the radial streamers, and notes consciously or subconsciously the rate at which the streamer velocities increase. This rate of increase tells him his rate of descent, because, as shown in Appendix 2, the streamer velocity at a given point in the visual field is inversely proportional to height, provided the forward velocity of the aircraft is constant. The reason why the pilot stares is that it is easier to judge the streamer pattern and the streamer velocity if he keeps his eyeballs fixed. It is, of course, well known that the parafovea is very sensitive to the motion of objects in the visual field, and that small departures from symmetry are easily detected.

(10) Deductions From Parafoveal Streamer Theory.

If this theory is substantially correct (and all the pilots with whom the writer has discussed it seem to think that it is) then a number of interesting deductions can be made from it. Some of these are given below.

(a) Approach lighting patterns should have an apex at a selected touch down point on the centre-line of the runway near the origin of the radio glide path, and should be symmetrical about the extended centre-line of the runway. In such patterns the lights will appear to stream symmetrically along lines drawn through the selected touch down point so long as the aircraft is moving along a path which intersects the runway at this point. If the aircraft is on a path which does not pass through this point, then the streamer patterns will be similar to those shown on Figs. 11 and 12. These are both very different from the pattern which the pilot would see if the aircraft were following the correct path. Both the crossbar and slopeline patterns meet this requirement, and it is significant that these systems have been found to provide better guidance than

those which do not. It should be noted that a single line on the left side of the approach does not meet this requirement.

(b) Indications such as the echelons in the slopeline patterns are only effective when the angular subtense of the pattern and the rate of change of the perspective image are small, because when they are large, i.e., from about 150 feet downwards, the pilot is preoccupied with the streamer pattern and streamer velocities, knowing that he has very little time in which to make corrections. It would therefore seem that the real functions of the slopelights are, firstly, to provide indications of proximity to ground by means of fixture size, and secondly, to identify the legs of the vee in a manner which can be instantly recognised. Indeed, it is probable that any pattern which complies with the requirement given in (a) above, and has a reasonable amount of texture, will give elevational guidance in the limiting conditions which is as good as that given by the slopeline system. In these conditions the elevational guidance given by the crossbar system may well be better than that provided by any other system because the crossbars emphasise the vertical component of the streamer velocity. As is shown by equation (1) in Appendix 2, this is inversely proportional to height, which means that crossbars are very good proximity indicators.

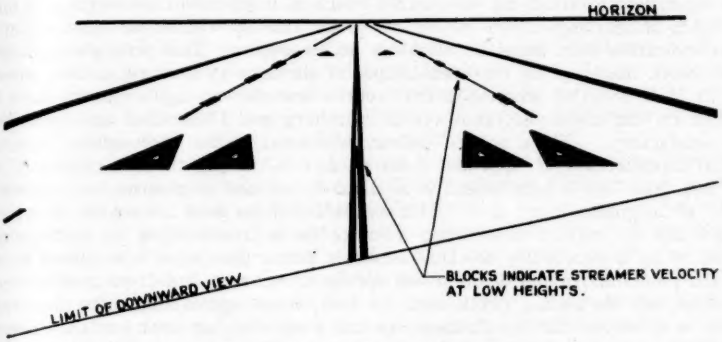
(c) If the deductions made in (a) and (b) above are justified, then the performance of the slopeline pattern would not be much affected if the slopelights in the 1,000 feet or so adjacent to the threshold were horizontal instead of being at 45 degrees to the horizontal. This is an important deduction because one of the chief objections to this system is that the slopelights form obstructions which will seriously damage an aircraft which is unfortunate enough to undershoot.

(d) Flashing lights should not be used to provide guidance because they break up the streamer pattern, and make it difficult to observe the streamer velocities. If flashing lights are used to help the pilot to identify the approach lighting system in the presence of extraneous lighting, then they should be superimposed on a pattern of steady burning lights which will provide the necessary guidance. However, as already mentioned in 5.1 identification can be achieved more cheaply and effectively by distinctiveness of pattern. Crossbars add greatly to the distinctiveness of any approach lighting pattern.

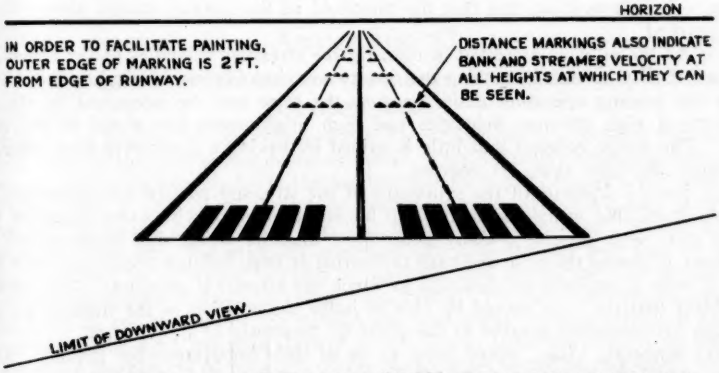
(e) If one of the main functions of crossbars is to make the streamer velocities more noticeable, then their number, spacing and width can be varied within limits to suit local conditions. For instance, if the limiting meteorological visibility for a six bar crossbar system with the bars spaced at 500 feet is 200 yards, then the limiting visibility for a three bar system with the bars spaced at 1,000 feet would be about 300 yards. It would, therefore, seem that a three bar system will be sufficient in many cases.

(f) If the important visual judgments are made by parafoveal vision, then, in the limiting conditions, runway markings of large size should be effective in providing guidance by day, and this has been amply confirmed by flight tests. As the size of aerodromes has increased, runways have become wider and smoother, and pilots have been robbed of much of the texture from which in the early days they made their judgments. Also, it is common for two or more runways to meet at the ends, and for both to intersect a taxiway, which means that, in bad visibility, the pilot's first sight of the runway is a large featureless expanse of concrete devoid of any directional or height indications whatsoever. He is therefore left without guidance at the very moment when he most needs it. This source of danger and many others, including those which arise from scale effects caused by differences in the widths of runways, can be overcome by the use of a system of markings such as that shown in Fig. 13. The writer regards runway markings as essential to any good system of visual aids.

(g) Equation (5) in Appendix 2 shows that S_H, the horizontal component of



VIEWPOINT 20 FT. VERTICALLY ABOVE ℄


HORIZON
IN ORDER TO FACILITATE PAINTING, OUTER EDGE OF MARKING IS 2 FT. FROM EDGE OF RUNWAY.
DISTANCE MARKINGS ALSO INDICATE BANK AND STREAMER VELOCITY AT ALL HEIGHTS AT WHICH THEY CAN BE SEEN.
LIMIT OF DOWNWARD VIEW.

VIEWPOINT 70 FT. VERTICALLY ABOVE ℄ & 100 YDS. FROM THRESHOLD

TO AVOID MISJUDGMENTS DUE TO CHANGES OF SCALE, THE DIMENSIONS SHOULD BE CONSTANT FOR ALL RUNWAYS. THE DIMENSIONS OF THE MARKINGS SHOWN IN THESE DIAGRAMS ARE AS FOLLOWS:-

OUTER STRIPES.	3 FT. WIDE, OUTER EDGES 146 FT. APART.
INTERMEDIATE STRIPES.	6 INCHES WIDE, CENTRES 75 FT. APART.
MIDDLE STRIPES.	6 INCHES WIDE; SPACE ALSO 6" WIDE.
BLOCKS.	18 INCHES WIDE X 20 FT. LONG, EVERY 100 FT.
THRESHOLD STRIPES.	7 FT. WIDE X 50 FT. LONG, SPACES 3 FT. WIDE.
DISTANCE MARKINGS.	500 FT. APART, ARROWS 10 FT. WIDE X 40 FT. LONG.

Fig. 13. Perspective diagram showing markings for instrument runways.

the streamer velocity, is independent of the height for given values of ϕ and w For runway lights at the edge of the runway ϕ is large and θ is small when the aircraft is low, and the vertical component, which is inversely proportional to height, is masked by a much larger horizontal component which is independent of height. It follows that lights or markings down the middle of the runway will be far more effective as height indicators than lights or markings at the edges. This principle explains the use of block markings on the inner stripes of the runway marking pattern shown in Fig. 13. It may be mentioned that centre line runway lights (green) have been installed on the instrument runways at Hamburg and Dusseldorf and have proved very satisfactory. These are, of course, additional to the edge lights.

(h) Equation (1) in Appendix 2 shows that S_V is negative, i.e., upwards, when θ is less than α, is zero when θ is equal to α, and is positive, i.e., downwards when θ is greater than α. This means that if the pilot can see his aiming point, he can tell by careful observation whether he is overshooting or undershooting because if he is proceeding towards a certain point, that point will appear to stand still, and points above and below it will appear to move up and down respectively. If he cannot see his aiming point, then his task, when approaching over the crossbar system, is to ensure that the furthest bar seen keeps moving downwards. If he does this, then it can easily be shown that the aircraft will depart very little from the radio glide path which it was presumably following when the pilot picked up the lights. The writer believes that this is the fundamental reason why pilots have found that the crossbar system provides good elevational guidance in bad visibility. Here again, the mental process involved is substantially the same as that used in good weather flying. It follows from this that the threshold of the runway should always be very well marked.

(i) As the pilot is interested in noticing the streamer velocities as far ahead as he can see, it may be that increasing the downward view beyond a certain point may not make the landing operation easier because the pilot may be distracted by the combination of high streamer velocities and high brightnesses just ahead of the cut-off line. The writer believes that little is gained by having a downward view during the approach of more than 20 degrees.

(j) Since judgments of the symmetry of the streamer pattern are important, there is little doubt that visual judgments will be easier to make with some shapes of windscreen than with others. Many pilots have told the writer that large aircraft with windows all round the nose are hard to control at first, because there is so little in the field of view to indicate the direction in which the aircraft is pointing. It is therefore important that the pilot should be able to judge the position of the trace of the plane through his viewpoint parallel to the plane of symmetry of the aircraft.

(k) Binocular vision would seem to be of little importance for landing. This is borne out by the fact that there are several cases on record where the loss of an eye seemed to have little effect on the pilot's ability to make good landings. It may well be that in testing pilots' eyes too much emphasis is laid on binocular vision, and that a good visual memory and a sensitive parafovea are more important.

(11) Concluding Remarks

The Arcata installation of the crossbar system was completed in September, 1949, and it is now being compared with the slopeline and other systems installed there. As the fittings used are small enough to appear as point sources, the Arcata crossbar system has insufficient texture, and its performance is somewhat inferior to the British installations which use fittings with flashed areas about six times as large. Nevertheless the tests which will be made there during the 1950 fog season may be expected to yield results of considerable interest. However, in the writer's opinion, these results can be correctly assessed only if they are related to some theoretical framework which is

sound as regards fundamentals. The parafoveal streamer theory is an important part of this framework, and without an understanding of it, assessments of the amount of guidance provided by the various systems will be largely dependent on subjective impressions and previous bias. It is also pointed out that some systems show up quite well in good or moderate visibility (this applies particularly to the slopeline system) and that it is under these conditions that most observers see them and form their opinions. The writer hopes that he has made it abundantly clear that no observer can form a reliable opinion as to the merits of a system unless he makes a large number of off-centre approaches on it under bad visibility conditions. The only alternative is a statistical appreciation based on operational experience.

The principles underlying the use of crossbars now seem to be generally accepted, and the question at issue is whether they shall be used with a centre line, as in the crossbar and American Air Line Pilot Association systems, with a line on the left side of the approach, as in the French system, or with a symmetrical vee, as in the slopeline system. Operational experience under conditions of high traffic density has already shown that the crossbar system gives indications which are both sensitive and easy to interpret. In addition, it is flexible and cheap, and is already in use in several countries. In some other countries the principle is strongly supported by pilot opinion. It would, therefore, appear that some pattern on this principle will eventually be accepted as a permanent international standard, although, perhaps, not the only one.

References

(1) E. S. Calvert, Journ. Royal Aeronautical Soc., July, 1948.
(2) K. G. Bergin, Journ. Royal Aeronautical Soc., Oct., 1949.

Appendix 1*

Some observations on manually flying an I.L.S. localiser beam

The I.L.S. localiser is commonly flown by systematically changing the aircraft heading until the localiser needle *ceases to move*. This particular heading is sometimes called the "*reference heading*." If the localiser needle is not at centre, the pilot must steer either left or right of the reference heading as required until centre indication is observed, at which moment the reference heading is again held. As the aircraft continues its approach, the pilot, by watching carefully for the first sign of needle motion, readjusts his reference heading to maintain zero movement. In practice this is a continuous process sometimes called "bracketing." Somewhere between approximately 3,500 ft. and the end of the runway the pilot *holds* his final reference heading and, providing the I.L.S. needles are within safe limits, continues toward the runway. Thus in effect the process of manually flying the localiser is one of choosing a heading which near the end of the approach will be *held*.

If the air is smooth, if the crosswind velocity is constant, and if the localiser beam is straight, the process of bracketing is simply the determination of *one* reference heading. However, in practice these idealised conditions seldom occur, so that as the aircraft proceeds down the localiser, bracketing actually involves the determination of a series of reference headings. If bracketing is continued too near the runway, however, it is likely that a localiser needle oscillation will develop, and the approach will fail. If a final reference heading has not been determined near the middle marker (approximately 3,500 ft. from the threshold) it is probable that the approach will have to be repeated. Under low visibility conditions with variable crosswinds aloft, *and with no visual aids*, 3 to 5 approaches may be required by an experienced crew to successfully accomplish a landing.

In practice it has not been uncommon to see 20 deg. of drift at the outer marker

*Contributed by the Flight Research Dept., Sperry Gyroscope Company.

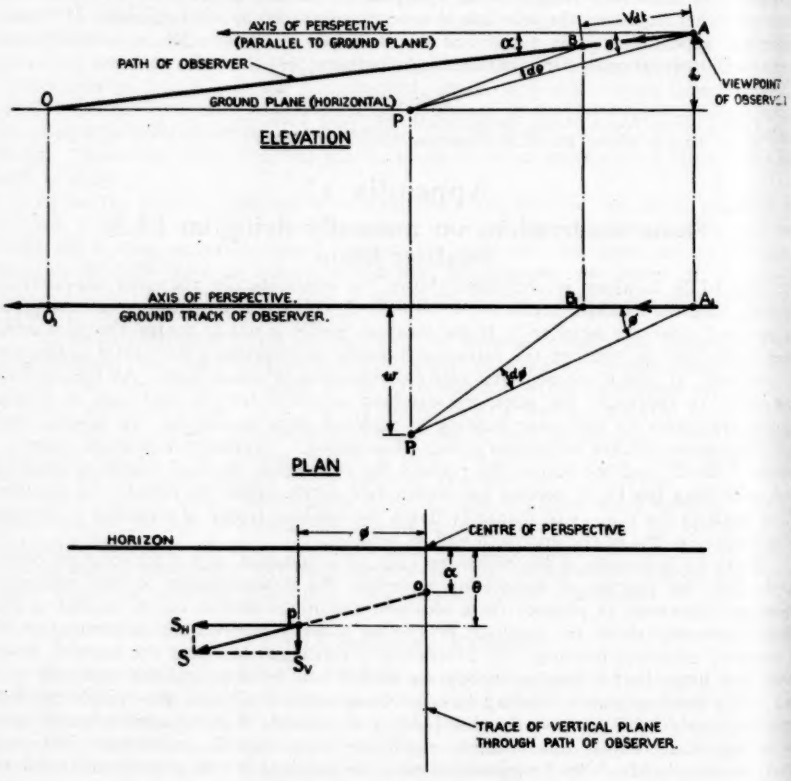
diminish to the order of 3 deg. at ground level. The rough air that often accompanies such a situation further adds to the difficulty of bracketing. Contrary to the opinion of some people, low visibilities in rain, snow, or fog can accompany such a situation.

The ability to hold heading is *the* important factor in flying the I.L.S. localiser beam. Rough air, fatigue, poor cockpit lighting, anoxia, difficulty in flying the Glide Slope, etc., effect performance noticeably. Since the ability to hold heading is directly dependent upon the ability to fly wings level, bank indication is of prime importance.

Appendix 11

Magnitude and Direction of Streamer Velocities at a Point in the Field of View

STREAMER VELOCITIES AT A POINT IN THE FIELD OF VIEW WHOSE PERSPECTIVE CO-ORDINATES ARE $\theta°$ BELOW THE HORIZON, AND $\phi°$ TO ONE SIDE OF THE VERTICAL PLANE THROUGH PATH OF OBSERVER. OBSERVER IS AT POINT A AND IS MOVING WITH VELOCITY V ALONG A STRAIGHT LINE WHICH MAKES AN ANGLE $\alpha°$ WITH THE HORIZONTAL AND INTERSECTS THE GROUND PLANE AT O. HEIGHT OF OBSERVER ABOVE GROUND IS h.



PERSPECTIVE DIAGRAM CORRESPONDING TO PLAN & ELEVATION SHOWN ABOVE

VERTICAL COMPONENT (S_V) OF STREAMER VELOCITY AT P

$$d\theta = \frac{V\,dt \sin(\theta-\alpha)}{h/\sin\theta}$$

$$S_V = \frac{d\theta}{dt} = \frac{V}{h}\left\{\sin(\theta-\alpha)\sin\theta\right\} \quad \text{.....(1)}$$

HORIZONTAL COMPONENT (S_H) OF STREAMER VELOCITY AT P

$$d\phi = \frac{V\,dt\cos\alpha\sin\phi}{d/\cos\phi} = \frac{V\,dt\cos\alpha\sin\phi\cos\phi}{h\cot\theta}$$

$$S_H = \frac{d\phi}{dt} = \frac{V}{2h}(\cos\alpha\sin 2\phi\tan\phi) \quad \text{.....(2)}$$

$$= \frac{V}{2h}(\sin 2\phi\tan\theta) \text{ when } \alpha \text{ is small} \quad \text{.....(3)}$$

RESULTANT STREAMER VELOCITY (S)

$$S = \sqrt{S_V^2+S_H^2}$$

$$= \frac{V}{2h}\sqrt{4\sin^4\theta+\sin^2 2\phi\tan^2\theta} \text{ when } \alpha \text{ is small.}$$

$$= \frac{V\tan\theta}{2h}\sqrt{\sin^2 2\theta+\sin^2 2\phi} \quad \text{.....(4)}$$

Direction of S is along line joining perspective projections of O and P, as shown at bottom left.

Equation (3) may be expressed in terms of w instead of θ by putting $\tan\theta = h/w\cot\phi$.

$$\text{then } S_H = \frac{V}{w}(\sin^2\phi) \quad \text{.....(5)}$$

Equation (4) also reduces to this when $\theta=0$.

NOTE. If h and w are in feet, and V is in feet/sec., then velocities are in radians/sec.

Discussion

CAPTAIN A. M. A. MAJENDIE (B.O.A.C.), who opened the discussion, showed films demonstrating the pilot's ocular technique on a normal approach and landing. He explained that the projector he was using was only a small one because it was impossible to put a normal 16 mm. camera in front of the pilot. The camera, an 8 mm. one, was positioned on the top of the pilot's instrument panel. The films were taken under ordinary airline route operating conditions. They were not taken under test conditions, and the pilots filmed, of which he himself was one, were all operating the No. 4 Line Route of B.O.A.C. He felt that this fact gave an enhanced value to the films.

The most notable feature was seen to be the almost total absence of vertical eye movements during the final stages of an approach and landing. Allowing a fixation time of 0.1 seconds for foveal vision, it could be shown that, for a normal

approach, the vertical eye movement required to hold this on a point on the landing surface close enough to reveal good texture, would be of the order of 5 deg. It could be seen from the films that eye movements down to an order of magnitude of about 1 deg. could be detected. It was, therefore, safe to assume that fixations on the landing surface were not being employed by the pilot in his judgment of the final stages of approach and landing.

In presenting the films Captain Majendie drew special attention to the movements of the pilots' eyes.

Mr. R. BROADBENT (Ministry of Civil Aviation) showed a coloured film taken from the air of the Crossbar system installed at London Airport. He said that during the last three years he had been in charge of aerodrome lighting matters in the Ministry of Civil Aviation and during that time had been in close association with Mr. Calvert through the Lighting Committee of the Ministry. It was particularly gratifying to hear this paper of Mr. Calvert's since he recalled that three years ago these same ideas were by no means accepted by illuminating engineers in general. Indeed, he believed they were not wholely accepted by some illuminating engineers in America at this moment but he believed they would be accepted eventually. However, the Ministry of Civil Aviation *did* accept Mr. Calvert's ideas on approach lighting as long as three years ago, perhaps because they knew Mr. Calvert better and because, according to the French philosopher, to know all was to forgive all! As Mr. Calvert had said, the Ministry decided to install a full cross-bar, or Calvert, system of approach lights at London Airport early in 1948 and this was the first of its kind to go into operational use. Since them, the system had operated successfully through two winters of bad visibility test flying.

During the winter of 1948-1949, the Ministry of Civil Aviation carried out a number of tests on the system, in visibilities ranging from 1,000 yards to 50 yards, and it had been found that the full seven bar system was satisfactory under test down to 80 yards visibility by night and 180 yards by day. Civil operating companies made landings during this period in visibilities well below those normally established as minima for airports equipped with other types of approach landing.

During the winter of 1949-50 the three bar Calvert system was found satisfactory down to 270 yards by night and 380 yards by day. During this time 14 passenger carrying aircraft made landings at London Airport in visibilities of less than 300 yards. Under these conditions many of the world's major airports were completely closed to passenger carrying aircraft: for example, Paris (Le Bourget) closed down in visibilities of less than 500 metres. It had, indeed, been said that London Airport was the best equipped airport in the world as far as aerodrome lighting was concerned.

The Crossbar system of approach lighting had been adopted by the Ministry of Civil Aviation as the standard high and low intensity system for civil airports. It was accepted, together with the French crossbar system and the American slopeline system, as a Recommended Practice by the Aerodromes and Ground Aids Division of the International Civil Aviation Organisation in November, 1949, and there were many indications that in course of time international standardisation would be on the lines of Mr. Calvert's system. It could safely be said, therefore, that Mr. Calvert's ideas had revolutionised the visual aids to approach and landing in poor visibility, and it was interesting to ask how they had done so since there were many urgent problems of a similar nature awaiting solution in the field of air transport. Briefly, it seemed that Mr. Calvert had successfully bridged the gap between the pilot and the engineer by an imaginative reconstruction of the pilot's problems based upon subjective analysis from first-hand experience. This experience, indeed, must have been very uncomfortable at times. He recalled a flight inspection of runway markings in very "bumpy" weather when Mr. Calvert, unknown to others around him, suffered all the miseries

of air sickness but, nevertheless, contrived to take away very useful impressions. He recalled, too, a test flight in the small hours of a very cold February morning when fog was very dense and widespread over Southern England and the nearest fog-free aerodrome was 300 miles away. Then it was a case of landing or staying aloft in a visibility of 80 yards until the fog cleared. He explained the position to Mr. Calvert who came aboard without a moment's hesitation.

Continuing, he said he did not wish to discuss the "parafoveal streamer" theory in detail, but within the experience of every pilot, the theory was valid during the final stages of approach and touch-down. It might be that the theory was more important in the use of runway lighting and runway marking than in approach lighting. How far the eye could scan a pattern and at the same time could accept and use data from the parafovea, he did not know. In his own experience of bad visibility test flying, the parafovea only took over when very small and accurate judgments had to be made. This was usually before landing since it was unusual to make the first contact on the lights with the aircraft correctly aligned at the right height and in the right attitude. The theory, however, added to our knowledge of how the pilot made visual judgments. It remained only to fit the pieces together to obtain a complete theory of visual judgment in relation to approach and landing, and he hoped that Mr. Calvert would be able to complete this.

CAPTAIN P. E. BRESSEY (British European Airways), whom the President said could speak on the matter from the pilot's point of view and also on behalf of the British Air Line Pilots Association, commented on the reference in the paper to the great gulf usually existing between the pilot and anyone presenting a system to help him land in bad visibility. But Mr. Calvert was very fortunate in being one of the very few men who was not a pilot, who could not only appreciate the difficulties of the pilot but, on quite a number of points, could explain what the pilot was thinking in a much more concise way than the pilot ever realised before. It was because Mr. Calvert had gone so deeply into the fundamentals of the matter that he had been able to simplify his system so that the pilot's reactions to it were immediate and automatic; and, therefore, the system had been very successful. The ordinary commercial pilot in Europe did not have to make really bad-visibility landings more than six times a year on an average, and those six really bad-visibility landings would be compressed into the winter fog period which lasted about three months. For the remaining nine months of the year the pilot was making landings under reasonably good conditions. It was obvious, therefore, that any system to help the pilot landing in fog could not be one involving a special technique, a great deal of experience, and constant practice to carry it out. Landings in a visibility of less than 800 yards were normally a strain on the pilot. The landing had to take place at the end of his trip when the pilot was tired and therefore he would not be in the best condition to carry out any difficult manoeuvres which a special technique might call for. With the Calvert system, however, experience had been that no very special effort on the part of the pilot was called for. He quoted several instances to show that even pilots who had not had experience of the system could land by it the first time with complete safety in visibilities of less than 400 yards. The Calvert system was now being used by pilots in conditions which, three years ago, would have made their hair stand on end. It was now possible for pilots with a little experience of the system to make safe landings with passengers in visibilities of less than 300 yards. That distance would be reduced as pilots gained experience on the system, and he believed that in a short time there would be virtually all-weather operation of aircraft at London Airport.

AIR COMMODORE J. W. F. MERER, Director of Navigation and Control, Air Ministry, discussed the use of the Calvert system in connection with the airlift operations in supplying the Western Section of Berlin. He said the system was first installed at Gatow in October, 1948, and the problem was to get aircraft into and out of Berlin with the closest possible intervals between, in all weather by day and by night. That interval was a matter of three minutes during which the aircraft had to land and taxi clear of the runway. In instrument flight conditions the interval between aircraft was five minutes and this was greatly assisted by the installation of the Calvert system of lighting used in conjunction with radar approach aids. Without that system of lighting it would have been impossible to have operated in the manner they did down to the minimum limits of half-a-mile visibility and cloudbase 200 feet. The pilots of these aircraft had to bear in mind that there was no time for making an error in landing and having another try for there was one aircraft in front and another coming up behind at intervals of five minutes. In this respect the Calvert system had been most successful.

Referring to glare, he expressed the view that aerodrome lighting should be considered as a whole. Hitherto the tendency had been rather to consider approach and runway lighting separately and the result was a system which was out of balance. Under the conditions in Germany it was found that the original runway lighting in use was not sufficiently brilliant with the result that the pilot was unable rapidly to adapt his vision from the brilliancy of the crossbar approach lighting to the relative dimness of the runway lighting. The intensity of the runway lighting was, therefore, increased and the sodium lights of the crossbar system were duplicated by filament lamps whose brilliancy could be controlled to suit the visibility conditions. This combination overcame the difficulty experienced by pilots in their visual adaptation. In his opinion the general aim should be to harmonise the whole of the lighting of the airfield, including approach, runway, taxi track and loading apron.

Commenting on the films shown by Captain Majendie, he said that he felt that Mr. Calvert's theory of parafoveal streamer effect was sound. It was most interesting to watch the intense concentration of the pilots' eyes during the last 200 ft. of the runway, which supported the theory.

MR. J. L. RUSSELL, referring to the remark by Mr. Calvert that some approach lighting systems cause the pilot to suffer from illusions, said that Vee systems, in which the approach lights were arranged in lines converging towards the touch-down point, gave rise to one particular illusion. When seen at the same time as the parallel lines of runway lights, the approach lights appeared to run downhill and the runway uphill. Mr. Waldram had predicted this false perspective, and Mr. Russell said he had noticed it when flying on the American Slope Line system. It might be significant that, according to American Press reports, one aircraft had landed in the approach zone and was wrecked, and two others nearly suffered the same fate at Los Angeles soon after the Slope Line system had been installed.

Referring to Air Commodore Merer's statement about the use of the Calvert system in Germany, he said that he had been particularly impressed with the clarity of the indications given when the system was suddenly seen after breaking through low cloud on an instrument approach. He had felt that had he been a pilot he would have had no difficulty in making the necessary corrections to the approach. Finally he paid a tribute to the Air Ministry Works Department engineers who were responsible for the installations in Germany. They installed ten complete systems in a few months, and one of them was installed in the record time of eleven days. This was a remarkably

fine achievement, even taking into account the emergency powers at the engineers' disposal.

MR. J. M. WALDRAM said that he had had the privilege of following Mr. Calvert's work for a good many years and of seeing his cyclorama. He thought the Society was to be congratulated on having this paper for its Transactions; it was a notable contribution to the art of lighting. There was no need to apologise for a paper directed mainly to geometry and to requirements, as Mr. Calvert suggested; for a thorough understanding of the requirements was a necessary preliminary to the design of any lighting equipment. He had been in America a few years ago and saw at Indianapolis Mr. Pearson's Slope Line system; he also saw a cyclorama at the Bureau of Standards, but he thought it was by no means so successful. It was a matter of some satisfaction to see Mr. Calvert's ideas being adopted in other countries, particularly his perspective charts, printed in U.S.A. with acknowledgments. In his view, perspective was a most important study for all illuminating engineers, and the author's system was the example, par excellence, of its value. Experience had shown how much could be learned by simulation of a visual problem in the laboratory, where all factors were under control. He felt the author had done less than justice to his experimental technique both in the present paper and the paper to the Royal Aeronautical Society; the optical mechanism of the "simulator" was most ingenious and should be reported.

This paper had shown clearly that this problem could not be tackled unless one knew what the pilot was doing: a mere passenger, who was not a pilot and did not know how the pilot made his judgments or used his instruments, could not appraise the value of a system of lighting. This was where the simulation technique, which the author had used to successfully in the laboratory, was so particularly useful, because there unskilled pilots could, in effect, fly for themselves in bad weather which was not possible in practice.

MR. J. W. SPARKE said that the parafoveal streamer theory enabled simple explanations to be given for a number of hitherto unexplained phenomena which had

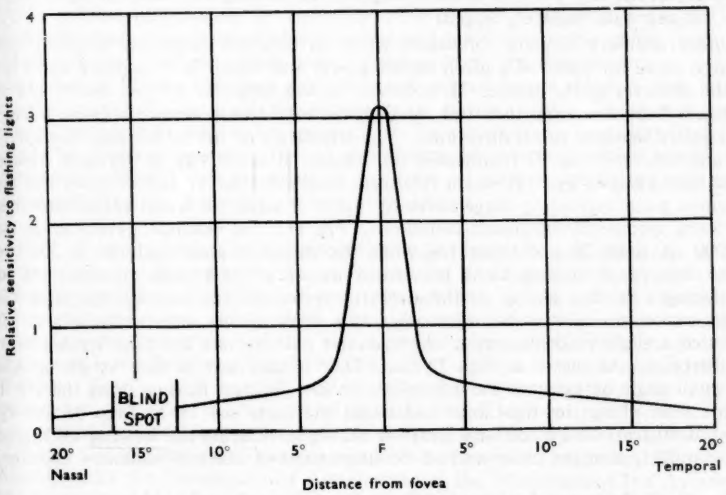


Fig. D1. Sensitivity distribution across the retina of the photopic eye.

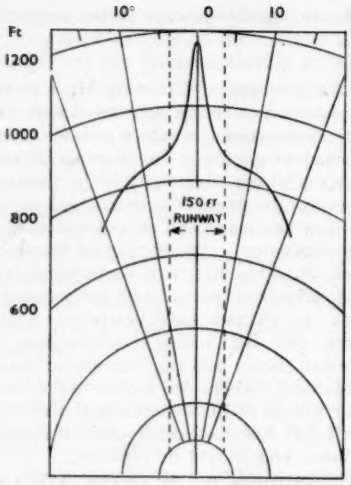


Fig. D2. Range curve for 5000 c.p. light, eyes fixated dead ahead.

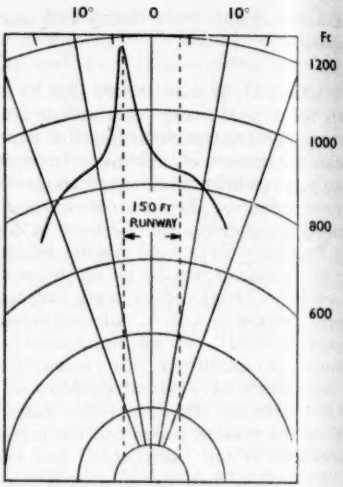


Fig. D3. Range curve for 5000 c.p. light, eyes fixated 4° left.

Daytime fog conditions
Meteorological visibility, 300 yards; Background brightness 300 candles/ft^2; Eye illumination on fovea, 650 mile candles.

been noted in connection with fog landings. For example, it had often been commented upon by pilots making a landing in fog that the runway lights do not gradually appear out of the fog, but that at some stage of the landing a number of lights forming a row on one side suddenly appear.

Under ordinary viewing conditions when an observer employed scanning vision, the range curve for lights of a given candle-power and which lie in a plane was a circle, with the observer at the centre. If, however, as was supposed by this theory, the pilot stared in a fixed direction, then this range curve would only remain a circle if the eye were equally sensitive in all directions. The sensitivity of the retina was, however, far from uniform, and Fig. D.1 indicated the change in sensitivity in different directions for the light-adapted eye. It was a relatively simple matter to deduce from this sensitivity curve a corresponding range curve for lights of some particular candle-power seen under some specified atmospheric conditions. Fig. D.2, for instance, gave a range curve for 5,000 cp. lights in a daytime fog when the meteorological visibility is 300 yards, and the observer is looking along the centre line of a 150-ft. wide runway. At some stage during a landing in fog, as the aircraft approached the runway, the pilot would become aware (probably sub-consciously) of a light to one side or the other. This constituted a slight discontinuity in the streamer pattern, and the pilot tended to look in its direction. As shown in Figs. D.2 and D.3, he had only to look by the comparatively small angle of 4 deg. to the left before he saw 330 feet farther along the left row of lights than along the right row and might therefore see up to four or five lights (spaced at 80 feet) on his left and none on the right. During the landing all this took place so quickly that the observer had the impression of one row suddenly appearing.

MR. R. C. MACLAREN said that Mr. Calvert admitted that no satisfactory theory

had been worked out to deal with the analysis of altitude indication on the line-and-bar system. Mr. R. E. Warren, of the Civil Aeronautics Administration, using perspective diagrams, claimed that the line-and-bar system was inadequate in this respect and that only Slope Line provided satisfactory altitude indication. Mr. Calvert suggested that this indication on the line-and-bar system was obtained from (a) the maintenance of a standard subtense of the bars as they passed below the nose of the aircraft; (b) texture indications from crossbar fittings; and (c) all visible bars being nearer the aircraft than the aiming point and therefore moving downwards. In theory (a) was satisfactory, but in practice it rather reminded one of the faith common to many flying instructors that, when landing on goose-neck flare path, a safe glide path could be assessed by checking the longitudinal subtense of the distance between the fittings. Of this theory it could only be said that some pilots were believers in the faith and others remained obstinately unconvinced. In practice again (b) did not seem valid in the lowest visibilities, say 100 yards by night, when even the crossbar lights appeared as point sources. The principle of (c) could be applied to any system where the most distant lights were paired, e.g., a funnel system.

Nevertheless, it was confidently held that it was almost impossible to undershoot on the line-and bar system. It would therefore appear that the system defined the ground plane almost as adequately as the evidence of this plane in good visibility by day. He suggested that the answer might be found in basic Euclidean geometry where, for schoolboy consumption, it was taken as axiomatic that a plane was determined in four ways: (1) by three non-collinear points; (2) by a straight line and a point outside it; (3) by two intersecting straight lines; and (4) by two parallel straight lines.

It would not be true to suggest that from an aircraft the ground plane was adequately defined by the first two or any one of these methods. If it were, almost any system of approach lighting would be adequate. He suggested, however, that the last two which were combined in the line-and-bar system gave to the pilot, by courtesy of Euclid, the complete determination of the ground plane required, as long as two bars could be seen simultaneously.

MR. W. A. VILLIERS referred to the competition between this country and the U.S.A. to get the best system of approach. Up to date, five countries, apart from Great Britain, had adopted Mr. Calvert's crossbar system, and some seven more were considering it very actively. That was a great triumph for this country.

He asked if Mr. Calvert had any ideas with regard to the solution of a problem which was constantly occurring in various parts of the world. There was quite a number of aerodromes where the approach to the runway was over deep and rough sea, and the problem was to arrive at some form of approach which would work. It seemed very difficult to have lights in any form of pattern under these conditions, and he would like Mr. Calvert's views on that matter.

MR. CALVERT, replying to the discussion, said that he would first like to thank Capt. Majendie for showing his film. This was a fine piece of work, and was all the more creditable in that it was done in the ordinary course of his duties as an operational air-line pilot. Mr. Calvert had always found pilots to be most co-operative once they became convinced that the engineers appreciated the difficulty of interpreting visual indications in a vehicle which had six degrees of freedom instead of the usual three. People often resented new ideas, even when they represented a change for the better, but except in one case, which perhaps Mr. Broadbent had in mind, he had had no trouble in obtaining a sympathetic hearing for his ideas from pilots both in this country and abroad, revolutionary as some of these ideas might be. He included in these remarks the Directorate of Aerodromes at the Ministry of Civil Aviation, to which Directorate Mr. Broadbent belonged. The military pilots showed the same

flexibility of mind when they asked for the system to be installed on the Air Lift. It was fortunate that they did, because the operational experience obtained during the winter 1948-1949 was invaluable, and had been largely instrumental in producing agreement as to the policy to be followed in this country.

He was particularly pleased to have Capt. Bressey's assurance that the crossbar system was easy to use in bad visibility, even when the pilot was tired, because that was the root of the matter. He thought, however, that the regularity of operations at an airport would be greatly improved if every pilot making an instrument approach could be given two items of information as follows:—

(a) the height on the approach path at which he would see enough of the guidance pattern to enable him to make a safe transition from instrument to visual flight.

(b) the length of the guidance pattern which he would see when crossing the threshold.

Item (b) could be observed with sufficient accuracy on the ground, but, as far as he knew, no practicable, reliable, and accurate method of finding (a) had yet been brought into operational use. He thought, however, that (a) could be measured directly by observations on a small captive balloon, and that this method would be reliable and sufficiently accurate. This would be tested during the coming winter, and, if successful, Capt. Bressey's hopes of virtually all-weather operation at London Airport might be realised in quite a short time. If it failed, then some other solution would have to be found, because until this problem was solved, the radio aids could not be operationally integrated with the visual aids without some element of risk. If this risk could be eliminated airports would be able to remain open except on those occasions when the conditions really were below the safe limits, and the utilisation factor would be substantially improved with corresponding reductions in operating costs. In this case it might even be worth while installing F.I.D.O.

He agreed very strongly with Air Commodore Merer that the visual aids should be considered as a whole. It would certainly be poor planning to install high intensity approach lighting in combination with low intensity runway lighting, and very low intensity taxiway lighting. The trouble was, of course, that most existing airfields already had low intensity runway and taxiway lighting with wide spacings, and it was expensive and difficult to convert these to high intensity and close spacings. He thought that there was considerable lack of balance even on some new airports, and that on some of these the difficulties of taxi-ing and ground movement control might limit both the utilisation factor and the traffic capacity. It was to try and avoid this at London Airport that he had put forward the most controversial of all his ideas, namely, the suggestion that the taxiway lights on the main routes should be on the centre-line.

As regards glare, he thought that the intensities used at night in approach lighting were often far too high. Increases in intensity beyond a certain point merely increased the glare without appreciably increasing the range. Approach lights should have several levels of intensity, say 50 candles for clear nights and cases where there was little extraneous lighting, 500 candles for poor visibilities at night or cases where there was much extraneous lighting, 5,000 candles for dawn and dusk and thick night fog, and 50,000 candles or more for daylight. If the runway lights were of low intensity it might prevent many complaints if a standing instruction were issued that approach lights should never be used at night at an intensity greater than 10 times that of the runway lights. If the approach and runway lights were of comparable intensity, as he thought they should be, then the maximum intensity at night should not exceed 10,000 candles.

Mr. Russell had referred to the downhill-uphill illusion which was so noticeable when converging lines were used in conjunction with parallel lines. Mr. Calvert thought that this illusion was dangerous for two reasons. In the first place, if the pilot

saw portions of both the runway and approach lighting patterns he might, if he had insufficient experience of the system, become confused as to the inclination of the ground plane and his height above it. In the second place, if he saw only a portion of the approach lighting pattern, and momentarily forgot that the lines converged (it was easy to do this on the slopeline system because the colours of the approach and runway lights were the same), then he would steepen his approach path in order to make the sum of the perspective angles increase, as it would do if the lines were parallel. In other words, he would tend to undershoot until he had learned that his task when approaching over converging lines was to keep the sum of the perspective angles constant, as explained in section 6.2 of the paper. It was therefore dangerous to use vee patterns on some airfields and parallel line patterns on others. Hardly any engineers except those who, like Mr. Waldram, had studied perspective, appreciated this fact, but he had been able to bring it home to some of them without tears by putting them on the cyclorama for a few sessions. It was to avoid dangers like this that international standardisation was necessary.

He was sure that Mr. Sparke would be pleased to hear Mr. Waldram's views about the ingenuity of the cyclorama. The instrument had been very useful as a research tool in that it had enabled him and his colleagues to check their theoretical work and to avoid many errors. (The report mentioned by Mr. Maclaren provided some interesting examples of such errors.) If the parafoveal streamer theory were correct, and he was very interested to know that Air Commodore Merer thought that it was, then it followed that one had to be careful in drawing conclusions as to the guidance provided by various systems from a study of ordinary perspective diagrams alone. They were, however, invaluable for finding spacings and for calculating the divergencies required from lights in various positions. Indeed, many problems of three-dimensional geometry which at first sight seemed to be intractable could be solved in a few minutes by means of these diagrams. The diagram in Appendix II of the paper was an example.

Mr. Sparke's work on the variation of sensitivity across the retina of the light-adapted eye had explained several things which had puzzled Mr. Calvert for some years. It also provided an additional reason why the pilot tended to hug one line of a two-line approach lighting system when the visibility was near the limit, the reason being that if the pilot looked at one of the lines, the other would appear to decrease markedly in brightness, and he might therefore remain unconscious of it during the few seconds that he was over the lights. It followed that a system which included a centre-line which the pilot could straddle, and by so doing keep the retinal image of the farthest light on or near the fovea, would have a higher effective intensity than those which did not. The data available at the moment indicated that the gain might be of the order of 10 times, but this was being checked with moving lights under conditions which simulated those of the actual full-scale problem.

Mr. Maclaren had raised the question of exactly how elevational guidance was obtained from approach lighting systems, and had referred to certain conclusions in a report* by Mr. R. E. Warren, of the Airport Development Division of the C.A.A. Mr. Calvert thought that there was no mystery about the main part of the answer, although there might be certain minor questions of a psychological or physiological nature which had yet to be cleared up. In the first place, all good approach lighting systems had textural qualities which gave the pilot an impression of his proximity to to the ground, but that was important only at low heights, say below 100 ft. The difficult part of the problem was to explain how the pilot judged whether or not he was travelling along a path which would bring him to the threshold at a height which would enable him to make a safe landing. He thought that the answer to this depended

* Perspective analysis of approach light patterns. Civil Aeronautics Administration. Technical Development Report No 96.

on the visibility. If the transition height was 150 ft. or below, then the explanation was to be found in the parafoveal streamer theory, and he believed that this was true of *all* systems. If the transition height was above this, then the pilot would see the threshold soon after transition and would watch this and try to fly so as to keep it at a constant angle below the horizon. If the horizon was not visible he would try to keep the threshold at a constant angle above the cut-off line, although changes in pitch confuse this indication. The echelon indications of the slopeline system would probably be of some use in this case. In other words, he thought that the echelon indications were unnecessary in good conditions, and unusable in bad conditions, but might be useful over a small range of visibilities in between.

The advantage which the crossbar system had over the other systems was that the crossbars made it easy for the pilot to notice apparent vertical movements in various parts of the pattern, and so enabled the pilot to use much the same technique throughout the whole range of visibilities. He agreed with Mr. Maclaren that there was no record in two years of operation of anyone undershooting or running off the runway when landing over the crossbar system, and as many bad weather landings had been made on it, there would seem to be little doubt that the system did in fact provide all the guidance that was necessary. Operational experience, if nothing else, therefore indicated that there was something wrong with Mr. Warren's conclusion that only the slopeline system provided " adequate " elevational guidance.

Another of Mr. Warren's conclusions was that the lateral error indications given by the crossbar system were " inadequate." The fact was that the superiority of the crossbar system in this respect was most marked, and had been commented on by almost every pilot who had used it, including some who had had much experience of the slopeline system. Indeed, the one thing upon which the Air Lift pilots were unanimous was that the crossbar system stopped " weaving." This agreed with theory, because a consideration of the rates of change of the two patterns showed that the sensitivity of the indications to displacements from the centre line was $1/h$ radians per foot for the crossbar system, as against $1/(2h)$ for the slopeline system, i.e., the crossbar system was exactly twice as sensitive. He thought that Mr. Warren had reached these wrong conclusions partly perhaps because of an unconscious bias towards the slopeline system, and partly because he had failed to appreciate that the motion of the observer enabled him to draw both directional and elevational information from the whole of the visual field, this information being additional to, and at low heights quite as important as, that which he obtained from the static pictures.

Mr. Warren's report did, however, make clear that the echelons in the slopeline system only provided elevational guidance if the pilot could distinguish a stepped-up echelon from a stepped-down echelon, and at the same time appreciate the meaning of nine different combinations. Mr. Calvert doubted if all pilots would be able to do this when hard pressed, because the indications were not of the kind which they were in the habit of using. If the pilot looked at one echelon, then the other was seen parafoveally, and if he looked straight ahead, as Mr. Calvert believed he did, then both were seen parafoveally. The two were very similar, and Mr. Calvert did not think that the acuity of the parafovea was sufficient to enable an observer in rapid motion to distinguish easily between them. Until someone had shown experimentally that this was possible, it was open to anyone to say that in bad visibility echelon indications only provided guidance to the pilots of helicopters, as this was the only type of aircraft in which the pilot had sufficient time to scan the pattern and work out his position.

If one accepted the practical disadvantages of three dimensional patterns, then one could think of several arrangements which might be as good or even better than the slopeline system. He had actually tried one such arrangement full scale, and had found that it worked quite well in moderate and good visibility, when, of course, it

was not needed. The parafoveal streamer theory had, however, convinced him that this was not a fruitful line of development.

Mr. Calvert did not think that any useful insight into the problem could be obtained from a study of Euclid's axioms. In Euclidean geometry the "determination" of a plane merely meant that a plane could be specified uniquely in certain ways, whereas the pilot used the word to denote his impression of his distance from a particular plane, i.e., the ground plane, and the attitude to it of the framework with which he identified himself. The fact that the same word was used in two senses did not mean that there was necessarily any connection between them.

He agreed with Mr. Villiers that no one could contemplate installing approach lights over water which was deep and rough. The only answer in this case was to install as much of the approach lighting system as was practicable, and use bold, contrasting markings on the runway. These markings facilitated the transition from instrument to visual flight, and increased the height at which the runway was picked up in daylight by about 50 ft. over a wide range of visibilities. This, taken in conjunction with the fact that there would be no obstructions in the approach, meant that it would be possible to use the Zero Reader or Automatic Approach down to lower heights than would otherwise be regarded as safe. New airports should, of course, be sited, so that some space was left for approach lighting on the instrument runway.

The Illuminating Engineering Society is not, as a body, responsible for the opinions expressed by individual authors or speakers.

With a view to avoiding possible confusion with other publications, reference to these Transactions should be in the form:—"Trans. Illum. Eng. Soc. (London)."

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